EDI CON 2019
Electronic Design Innovation Conference
电子设计创新大会

April 1-3, 2019
China National Convention Center
Beijing, China

Exhibition Hours
April 1: 11:00-17:00
April 2: 9:30-17:00
April 3: 9:30-13:00

# Improve Doherty Amplifier in efficiency and output power

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# What’s on offer?

- According to Darraji et.al, the difference between two solutions
  - Analog Doherty
  - Digital Doherty

  is as much as:

  - **60% output power**
  - **20% efficiency**
  - **50% bandwidth**
  - no degradation in DPD efficacy.
- But, how can the difference be identified on a case-by-case basis?

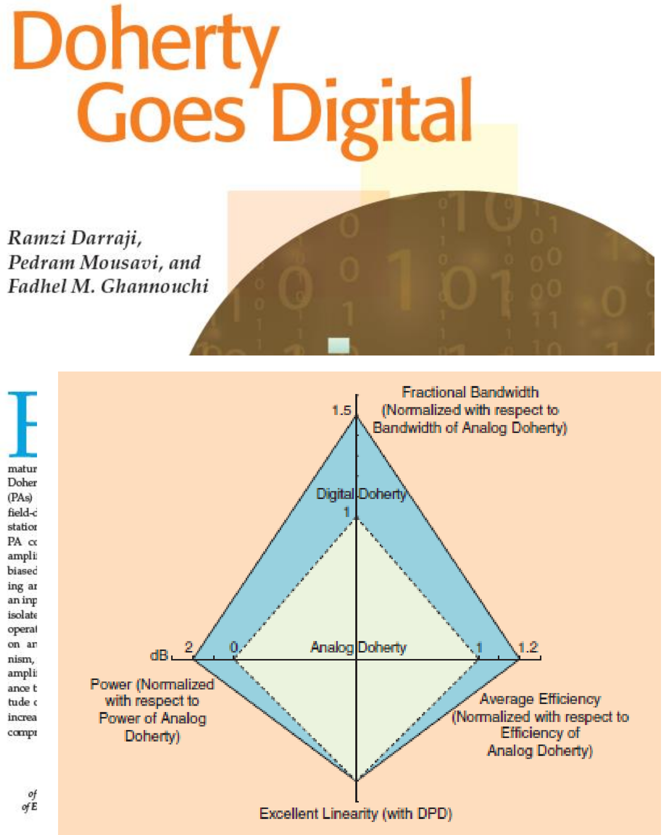


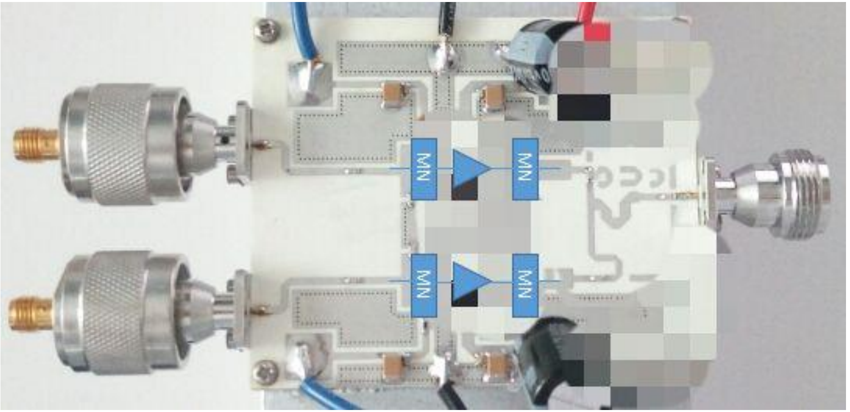

Figure 14. *Anticipated improvements in the RF performance of analog Doherty PAs using digital techniques.*

# Background on Doherty architecture

**Facts**
- Invented almost 100 years ago
- Efficiency enhancement method
- Linearity-preserving
- Two (or more) amplifiers that interact through a special combining network

**Applications**
- Mostly for below 3 GHz until now
- Dominates on base station infrastructure

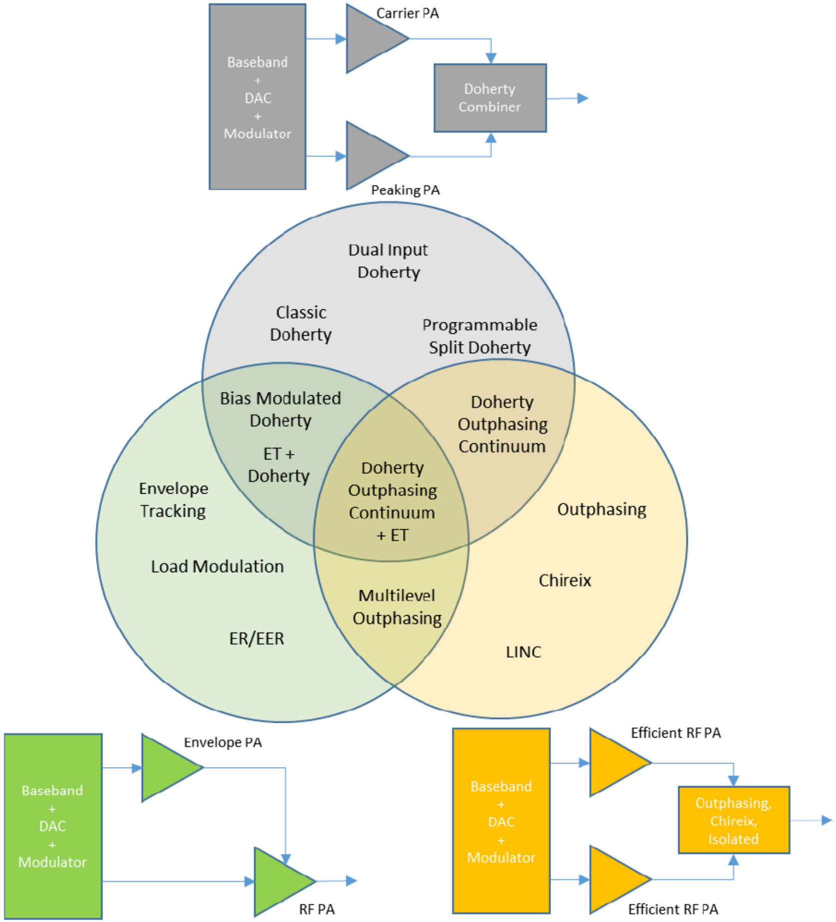
**New Frontier**
- Higher carrier frequencies, wider BW
- 5G in mmW, SatCom (Ku-, Ka-bands)



# Background

- Various possibilities of efficiency-enhancement architectures

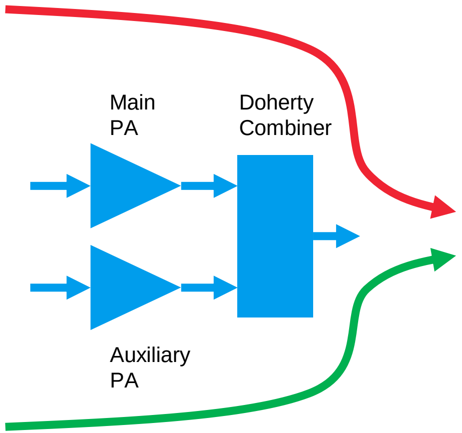
- Doherty amplifier is just one



# Challenge 1: Combining the 2 paths

- Misalignment of signals
  - loss of power
  - loss of energy efficiency
  - destructive voltages/currents

- Input signals need to be matched for amplitude and phase
  - Time domain
  - Frequency domain
  - Amplitude domain



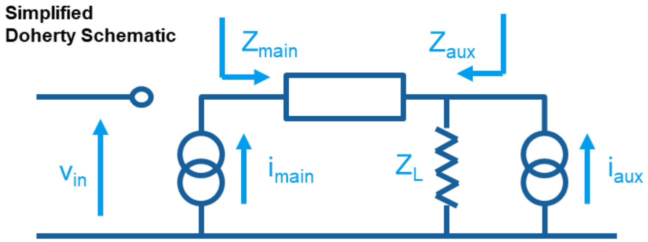

**Two paths of the Doherty Amplifier**

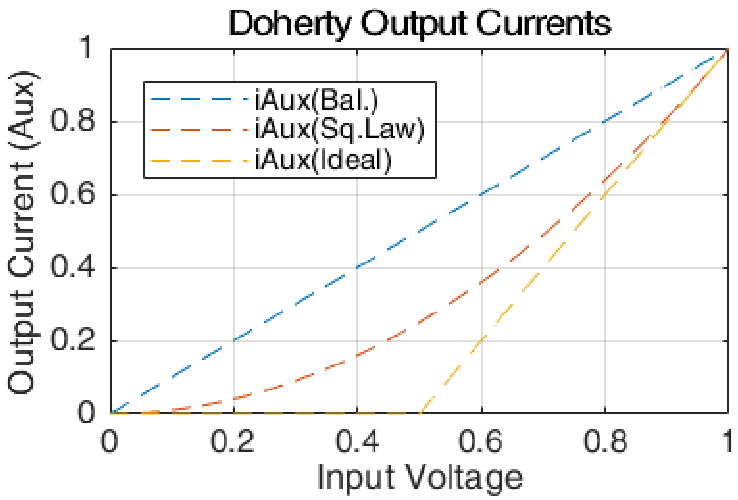
# Challenge 2: 2 different paths

- Ideal performance by auxiliary characteristic is “dog leg”
  - Often approximated by “Class C” amplifier

- Performance driven by difference between the main and auxiliary curves

- The two extremes
  - Main, the Doherty ‘effect’ tends to 0 (or like ‘Balanced’)
  - Ideal, the Doherty ‘effect’ is maximized



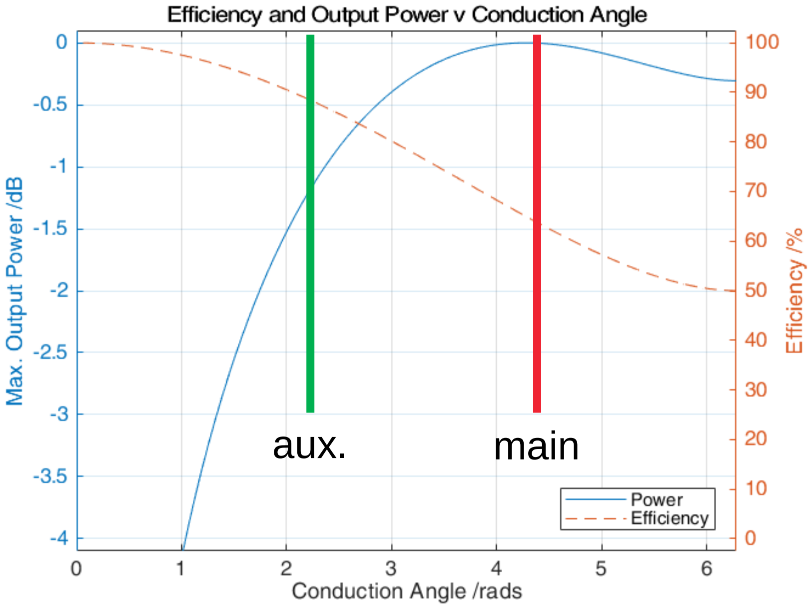



# Challenge 3: Find right amplifier setup for 2 paths

- Different classes of amplifier to drive the Doherty difference engine can be disadvantageous

- The Fourier Analysis of conduction angle shows how, power and efficiency might be compromised.
  - Power is lost from the auxiliary
  - Efficiency is lost from the main

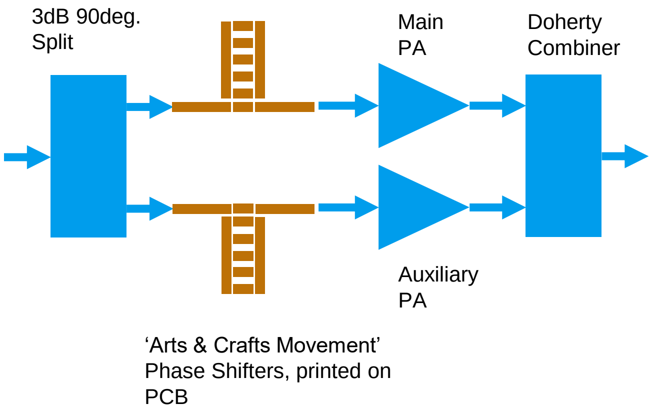
- The quiescent bias power demands of the main can prove costly, especially in TDMA operation.




**Power and Efficiency impacts of conduction angle [Cripps].**

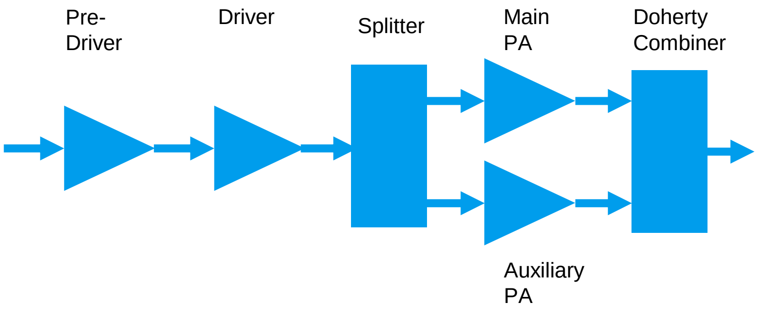
# Challenge 4: Signal splitter

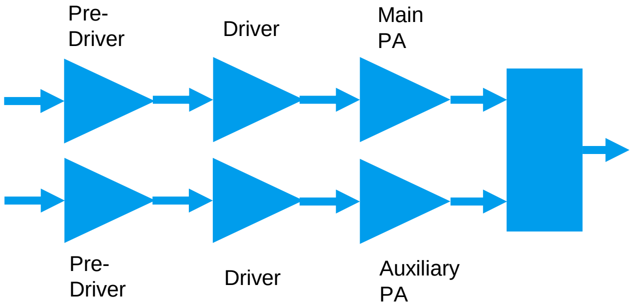
- How to design the input splitter?
- After design and alignment of the output section, designers often use cut-and-try techniques on the input side.
- Salient features of this method:
  - Labour intensive
  - Non-exhaustive, sparse characterization
  - Global maxima unconfirmed
  - Cannot easily adjust amplitude balance
  - Poorly defined structures
  - Lossy components
  - Matching variations



# Opposite Ends of the Spectrum

- Extremes of Doherty implementations:
  - The default setup
    - Single gain stage inside a Split-Doherty Combine.
    - Differentially biased devices
  - Digital Doherty
    - Independent paths all the way from digital domain
    - Common biased devices
- In between lies a whole range of implementation solutions, with differing features and trade-offs

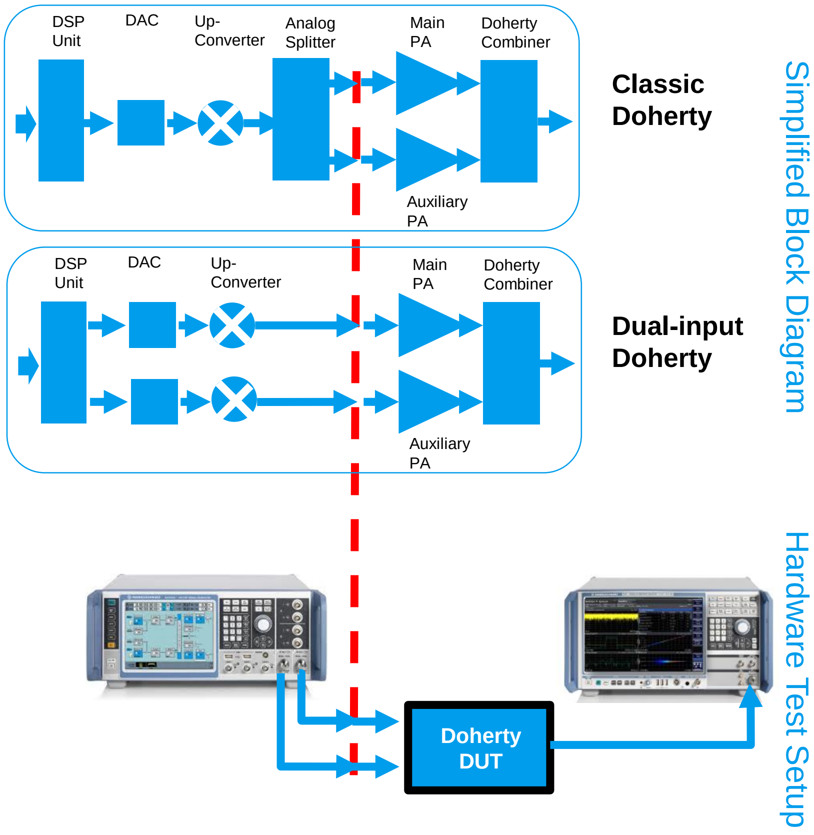


# Measurement aided development

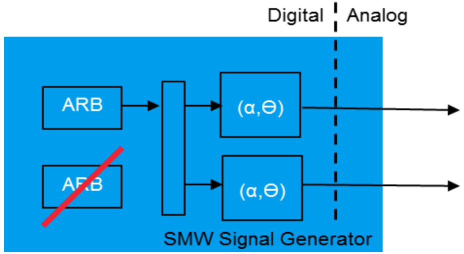
- **Idea**
  - Additional measurement-based step in the traditional Doherty development process
  - Remove the input split and phase shift networks
  - Drive two Doherty input ports directly from a signal generator

- **Benefits**
  - Better view of performance tradeoffs
  - In-depth understanding of sensitivities
  - Benchmark maximum performance
  - Select best input split and specify performance with confidence
  - Applicable to all input split architectures




**The test and measurement concept**

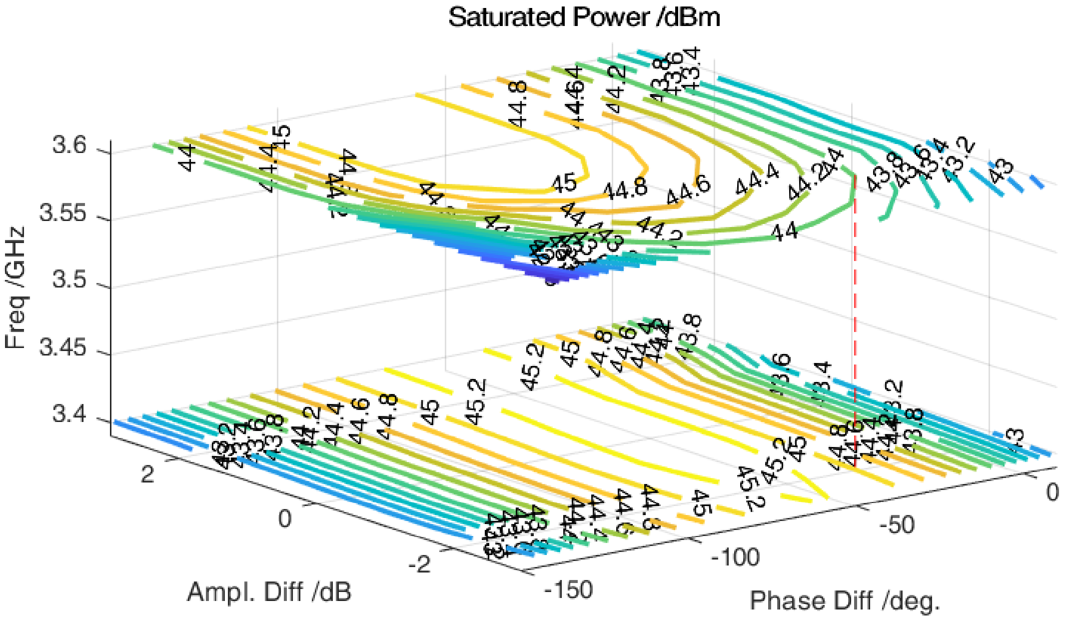
# Dual-Path Measurement (Linear)




- Same signal to both RF paths

- Sweep input power, amplitude and phase difference (optionally bias, etc.)

- Measure what is of interest like saturated power, RMS, PEP, Efficiency, ACLR or PAPRo



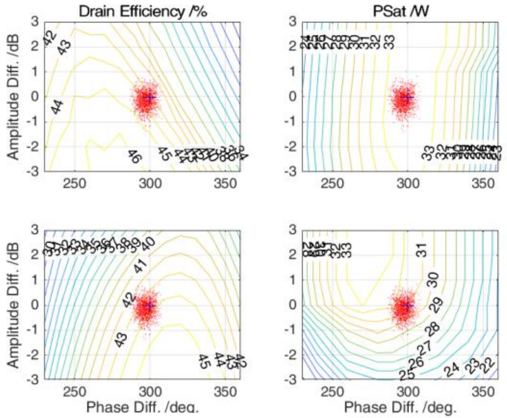

**Result:**

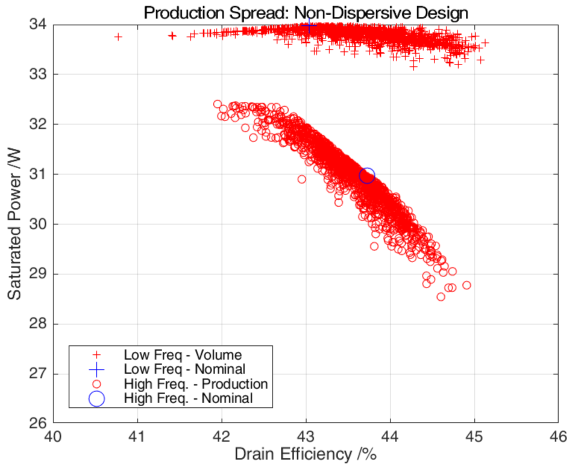
- Dispersion of amplitude/phase between parameter optima and frequency

- **This is already far ahead of the usual characterization dataset.**

# Apply mean variance

- Simulation of production variation vs gain and phase
- In this case, die-die variation superimposed on wafer-wafer variation
- Then spread it over frequency range using measurement data as a LUT

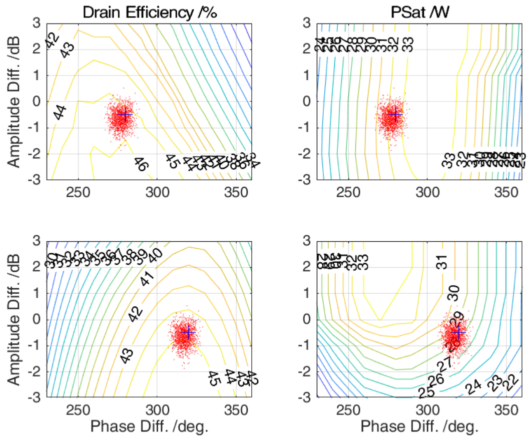


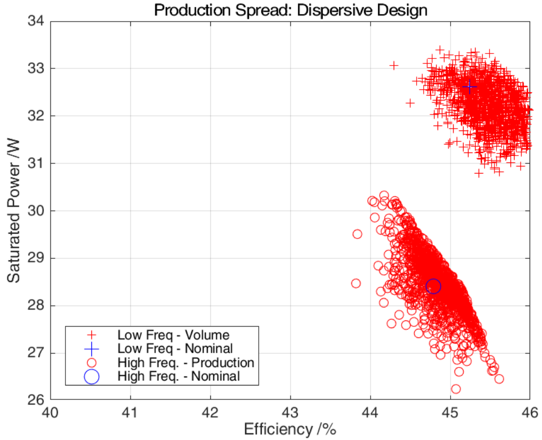



# Slight variation: equalized input

- **Different input split**, optimized for efficiency at the two design frequencies

- Apply the same randomized population of gain-phase spread across wafer and die – and the same post-processing…

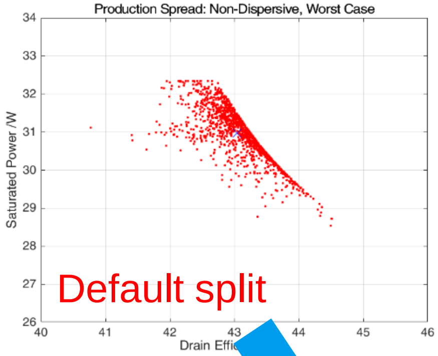


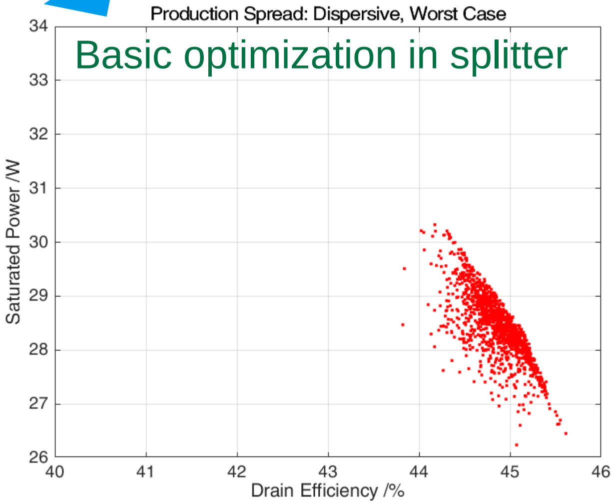



# Increased mean, reduced deviation

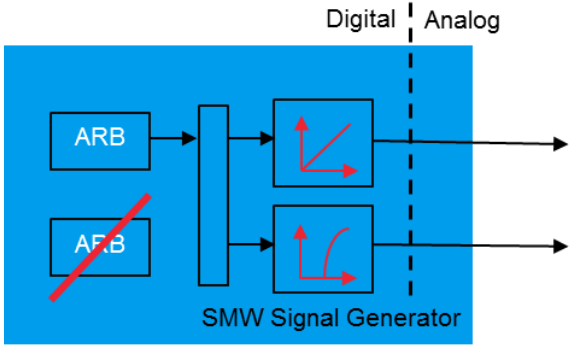
- Goal: optimized efficiency, we get on top
  - Increased mean value
  - Reduced standard deviation
  
  → improved specification

- Even a simple modification to the design flow and analysis can have significant improvements and consequences



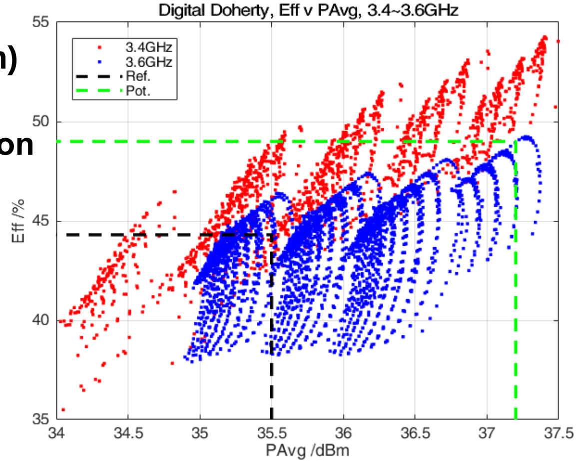
# Dual-Path Measurement (Non-Linear)

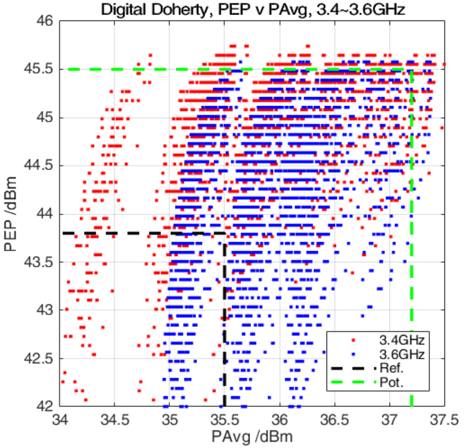



- Apply different, but related signals to the two RF paths and common-mode biasing. Simple case:
  - Auxiliary signal derived from square of the Main signal
  - Biased at threshold

- Driven by the increased saturated power (representing the limit of linearization)
  - **47% higher output power (43,8dBm -> 45,5dBm)**
  - **11% higher efficiency (44% -> 49%)**
  - **94% reduction in "stand-by" power consumption** (100mA->6mA)

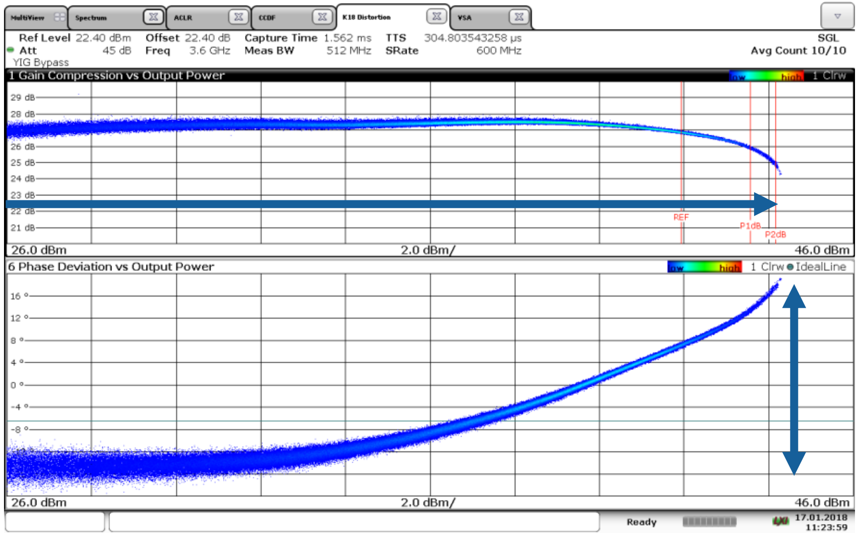
- Compare with the reported 60% output power, 20% efficiency, 50% bandwidth and no degradation in linearizability.



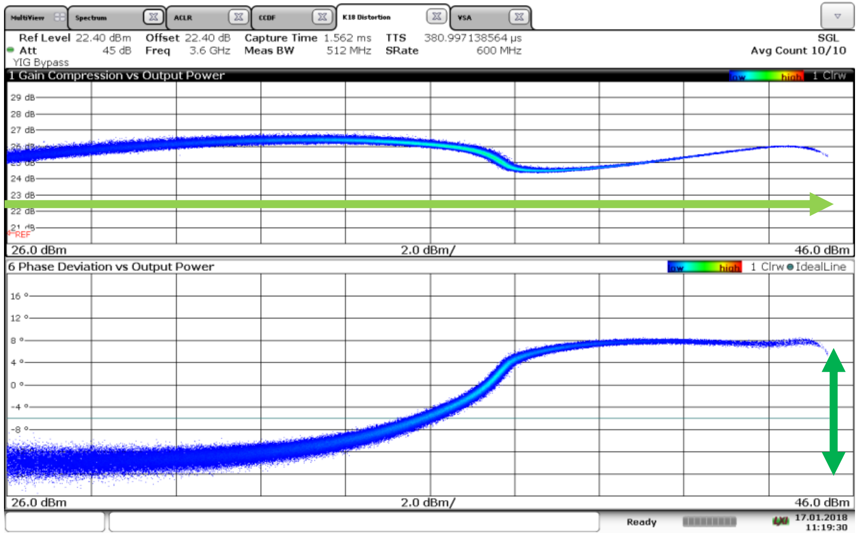



# Results

## Conventional Mode Operation



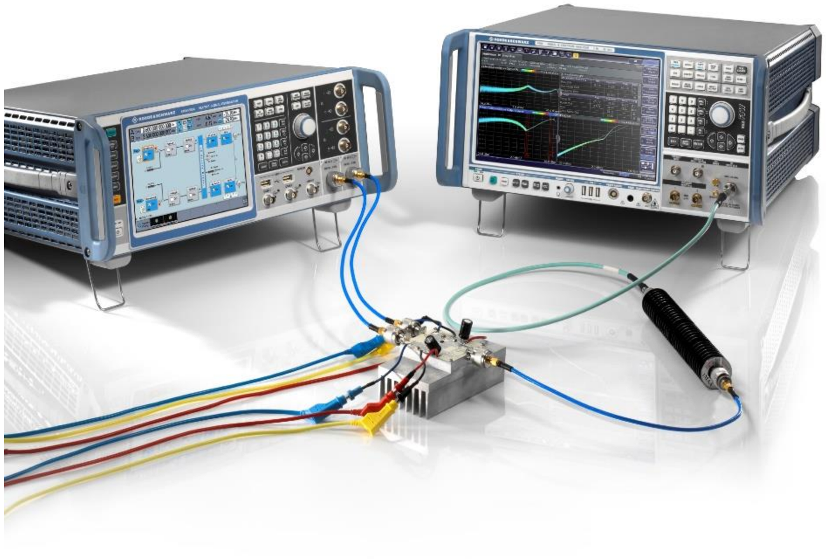

## Dual-Input Mode Operation



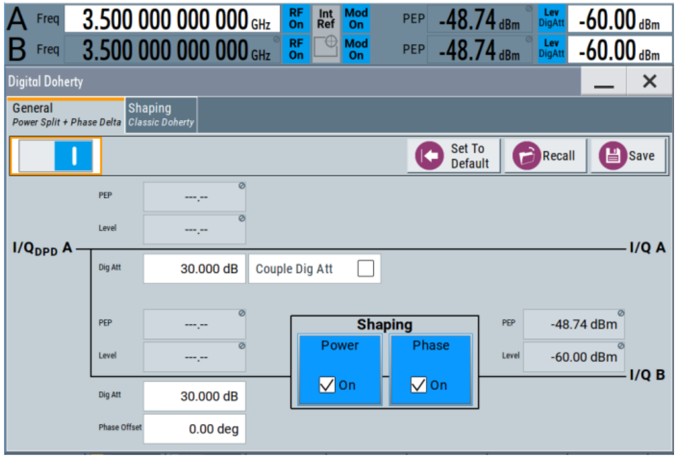
# Hardware

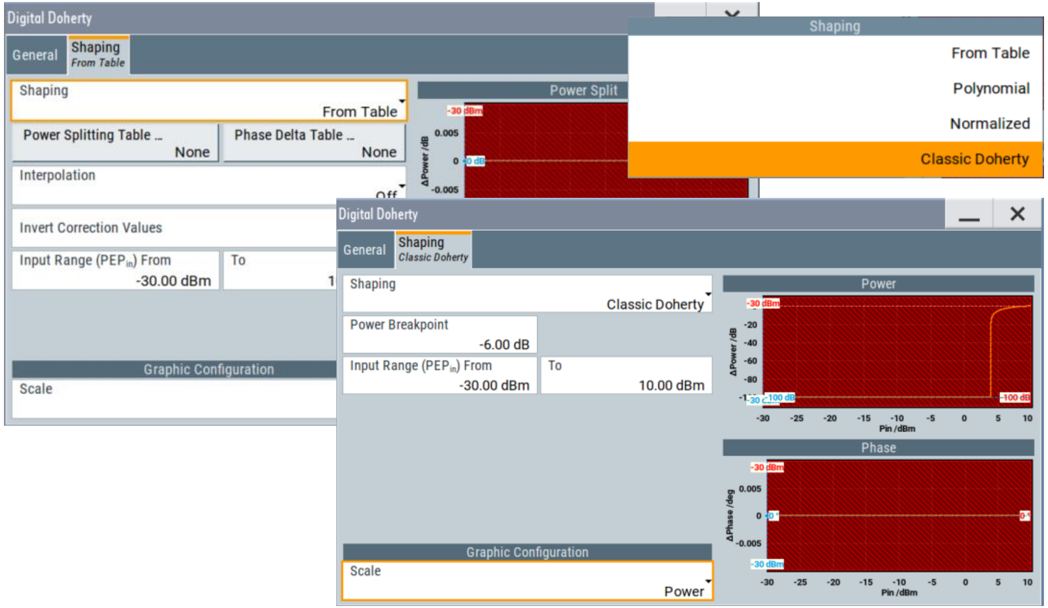
- **R&S®SMW200A Vector Signal Generator**
  - Dual-path with precise signal alignment
  - Relative phase, amplitude, timing adjustment
  - Power split and input-power dependent phase delta in real time
  - Shaping

- **R&S®FSW Signal and Spectrum Analyzer**
  - Wide analysis bandwidth
  - Dedicated amplifier test capabilities with all interesting parameters from EVM to Gain compression
  - Vectors like AM-AM and AM-PM



# R&S®SMW-K546 Digital Doherty Software Option




- Couple RF paths with precise phase and power alignment
- Power split and input-dependent phase delta
- Arbitrary delta-power, delta-phase

# Conclusions

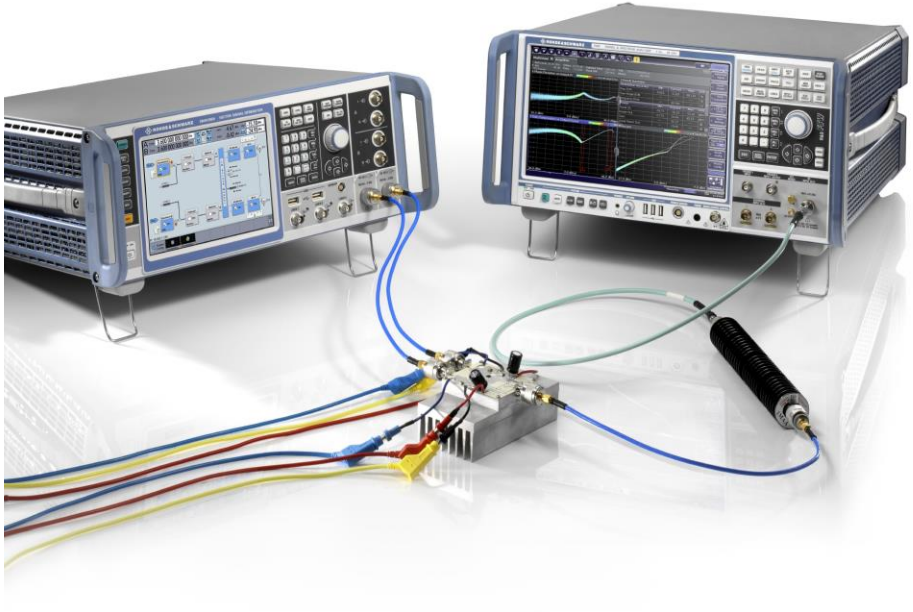
- Perfect Doherty operation cannot be achieved. But, performance can be strongly differentiated by the input side architecture.

- Various input side designs for the Doherty amplifier, including:
  - Fixed constant, or fixed dispersive, RF split
  - Programmable RF split
  - Dispersive RF split
  - Digital domain split

  … and so on, each correcting frequency, time or amplitude domain effects.

- The proposed measurement set-up enables a comprehensive, rapid and accurate characterization of the Doherty Prototype.

- **Measuring as a Dual-Input:**
  - **Provides unprecedented insight.**
  - **Enables the best engineering decision to be made, supported by the most information, in the shortest time.**



# References, Acknowlegements & Further Reading.

1. Cripps, S. C. (2006). "*RF Power Amplifiers for Wireless Communications". *Norwood, MA: Artech House.

2. Darraji, R., Mousavi, P., & Ghannouchi, F. (2016, Aug). "*Doherty goes Digital*". IEEE Microwave Magazine, 41-51.

3. Lloyd, P. G. (2016). "*Outphasing, Envelope & Doherty Transmitter Test & Measurement*". Rohde & Schwarz Application Note.
   - http://www.rohde-schwarz.com/appnote/1MA289